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WO 03/008607 A2

(54) Title: PROCESS FOR THE PREPARATION OF L-AMINO ACIDS USING STRAINS OF THE ENTEROBACTERIACEAE FAMILY

(57) Abstract: The invention relates to a process for the preparation of L-amino acids, in particular L-threonine, in which the following steps are carried out: a) fermentation of microorganisms of the Enterobacteriaceae family which produce the desired L-amino acid and in which at least one or more of the genes chosen from the group consisting of phoA, phnC, phnD, phnE, phnF, phnG, phnJ, phnK, phnL, phnM, phnN, phnO, phnP, eda, rpiB, zwf, mopA, pstA, pstB, pstC, pstS, ugpB, ugpA, ugpE, ugpC, ugpQ, dnaK, dnaJ, clpB, rpoE, htpG, ompF, ompC, aspA, gltA, sdhB, aceB and aceK, or nucleotide sequences which code for these, is or are enhanced, in particular over-expressed, b) concentration of the desired L-amino acid in the medium or in the cells of the bacteria, and c) isolation of the desired L-amino acid.

**Process for the Preparation of L-Amino Acids using Strains  
of the Enterobacteriaceae Family**

**Field of the Invention**

This invention relates to a process for the preparation of  
5 L-amino acids, in particular L-threonine, using strains of  
the Enterobacteriaceae family in which at least one or more  
of the genes chosen from the group consisting of phoA,  
phnC, phnD, phnE, phnF, phnG, phnJ, phnK, phnL, phnM, phnN,  
phnO, phnP, eda, rpiB, zwf, mopA, pstA, pstB, pstC, pstS,  
10 ugpB, ugpA, ugpE, ugpC, ugpQ, dnaK, dnaJ, clpB, rpoE, htpG,  
ompF, ompC, aspA, gltA, sdhB, aceB and aceK is (are)  
enhanced.

**Prior Art**

L-Amino acids, in particular L-threonine, are used in human  
15 medicine and in the pharmaceuticals industry, in the  
foodstuffs industry and very particularly in animal  
nutrition.

It is known to prepare L-amino acids by fermentation of  
strains of Enterobacteriaceae, in particular Escherichia  
20 coli (E. coli) and Serratia marcescens. Because of their  
great importance, work is constantly being undertaken to  
improve the preparation processes. Improvements to the  
process can relate to fermentation measures, such as e.g.  
stirring and supply of oxygen, or the composition of the  
25 nutrient media, such as e.g. the sugar concentration during  
the fermentation, or the working up to the product form, by  
e.g. ion exchange chromatography, or the intrinsic output  
properties of the microorganism itself.

Methods of mutagenesis, selection and mutant selection are  
30 used to improve the output properties of these  
microorganisms. Strains which are resistant to  
antimetabolites, such as e.g. the threonine analogue  $\alpha$ -  
amino- $\beta$ -hydroxyvaleric acid (AHV), or are auxotrophic for

metabolites of regulatory importance and produce L-amino acid, such as e.g. L-threonine, are obtained in this manner.

5 Methods of the recombinant DNA technique have also been employed for some years for improving the strain of strains of the Enterobacteriaceae family which produce L-amino acids, by amplifying individual amino acid biosynthesis genes and investigating the effect on the production.

## 10 Object of the Invention

The object of the invention is to provide new measures for improved fermentative preparation of L-amino acids, in particular L-threonine.

## Summary of the Invention

15 The invention provides a process for the fermentative preparation of L-amino acids, in particular L-threonine, using microorganisms of the Enterobacteriaceae family which in particular already produce L-amino acids and in which at least one or more of the nucleotide sequence(s) which  
20 code(s) for the genes phoA, phnC, phnD, phnE, phnF, phnG, phnJ, phnK, phnL, phnM, phnN, phnO, phnP, eda, rpiB, zwf, mopA, pstA, pstB, pstC, pstS, ugpB, ugpA, ugpE, ugpC, ugpQ, dnaK, dnaJ, clpB, rpoE, htpG, ompF, ompC, aspA, gltA, sdhB, aceB and aceK is (are) enhanced.

## 25 Detailed Description of the Invention

Where L-amino acids or amino acids are mentioned in the following, this means one or more amino acids, including their salts, chosen from the group consisting of L-asparagine, L-threonine, L-serine, L-glutamate, L-glycine,  
30 L-alanine, L-cysteine, L-valine, L-methionine, L-isoleucine, L-leucine, L-tyrosine, L-phenylalanine, L-

histidine, L-lysine, L-tryptophan and L-arginine. L-Threonine is particularly preferred.

The term "enhancement" in this connection describes the increase in the intracellular activity of one or more  
5 enzymes or proteins in a microorganism which are coded by the corresponding DNA, for example by increasing the number of copies of the gene or genes, using a potent promoter or a gene or allele which codes for a corresponding enzyme or protein with a high activity, and optionally combining  
10 these measures.

By enhancement measures, in particular over-expression, the activity or concentration of the corresponding protein is in general increased by at least 10%, 25%, 50%, 75%, 100%, 150%, 200%, 300%, 400% or 500%, up to a maximum of 1000% or  
15 2000%, based on that of the wild-type protein or the activity or concentration of the protein in the starting microorganism.

The process comprises carrying out the following steps:

- 20 a) fermentation of microorganisms of the Enterobacteriaceae family in which one or more of the genes chosen from the group consisting of phoA, phnC, phnD, phnE, phnF, phnG, phnJ, phnK, phnL, phnM, phnN, phnO, phnP, eda, rpiB, zwf, mopA, pstA, pstB, pstC, pstS, ugpB, ugpA, ugpE, ugpC, ugpQ,  
25 dnaK, dnaJ, clpB, rpoE, htpG, ompF, ompC, aspA, gltA, sdhB, aceB and aceK is (are) enhanced,
- b) concentration of the corresponding L-amino acid in the medium or in the cells of the microorganisms of the Enterobacteriaceae family, and
- 30 c) isolation of the desired L-amino acid, constituents of the fermentation broth and/or the biomass in its entirety or portions (> 0 to 100 %) thereof especially remaining in the product.

The microorganisms which the present invention provides can produce L-amino acids from glucose, sucrose, lactose, fructose, maltose, molasses, optionally starch, optionally cellulose or from glycerol and ethanol. They are  
5 representatives of the Enterobacteriaceae family chosen from the genera *Escherichia*, *Erwinia*, *Providencia* and *Serratia*. The genera *Escherichia* and *Serratia* are preferred. Of the genus *Escherichia* the species *Escherichia coli* and of the genus *Serratia* the species *Serratia*  
10 *marcescens* are to be mentioned in particular.

Suitable strains, which produce L-threonine in particular, of the genus *Escherichia*, in particular of the species *Escherichia coli*, are, for example

Escherichia coli TF427  
15 Escherichia coli H4578  
Escherichia coli KY10935  
Escherichia coli VNIIGenetika MG442  
Escherichia coli VNIIGenetika M1  
Escherichia coli VNIIGenetika 472T23  
20 Escherichia coli BKIIM B-3996  
Escherichia coli kat 13  
Escherichia coli KCCM-10132.

Suitable L-threonine-producing strains of the genus *Serratia*, in particular of the species *Serratia marcescens*,  
25 are, for example

*Serratia marcescens* HNr21  
*Serratia marcescens* TLr156  
*Serratia marcescens* T2000.

Strains from the Enterobacteriaceae family which produce L-  
30 threonine preferably have, inter alia, one or more genetic or phenotypic features chosen from the group consisting of: resistance to  $\alpha$ -amino- $\beta$ -hydroxyvaleric acid, resistance to thialysine, resistance to ethionine, resistance to  $\alpha$ -

- methylserine, resistance to diaminosuccinic acid, resistance to  $\alpha$ -aminobutyric acid, resistance to borrelidin, resistance to rifampicin, resistance to valine analogues, such as, for example, valine hydroxamate,
- 5 resistance to purine analogues, such as, for example, 6-dimethylaminopurine, a need for L-methionine, optionally a partial and compensatable need for L-isoleucine, a need for meso-diaminopimelic acid, auxotrophy in respect of threonine-containing dipeptides, resistance to L-threonine,
- 10 resistance to L-homoserine, resistance to L-lysine, resistance to L-methionine, resistance to L-glutamic acid, resistance to L-aspartate, resistance to L-leucine, resistance to L-phenylalanine, resistance to L-serine, resistance to L-cysteine, resistance to L-valine,
- 15 sensitivity to fluoropyruvate, defective threonine dehydrogenase, optionally an ability for sucrose utilization, enhancement of the threonine operon, enhancement of homoserine dehydrogenase I-aspartate kinase I, preferably of the feed back resistant form, enhancement
- 20 of homoserine kinase, enhancement of threonine synthase, enhancement of aspartate kinase, optionally of the feed back resistant form, enhancement of aspartate semialdehyde dehydrogenase, enhancement of phosphoenol pyruvate carboxylase, optionally of the feed back resistant form,
- 25 enhancement of phosphoenol pyruvate synthase, enhancement of transhydrogenase, enhancement of the RhtB gene product, enhancement of the RhtC gene product, enhancement of the YfiK gene product, enhancement of a pyruvate carboxylase, and attenuation of acetic acid formation.
- 30 It has been found that microorganisms of the Enterobacteriaceae family produce L-amino acids, in particular L-threonine, in an improved manner after enhancement, in particular over-expression, of at least one or more of the genes chosen from the group consisting of
- 35 phoA, phnC, phnD, phnE, phnF, phnG, phnJ, phnK, phnL, phnM, phnN, phnO, phnP, eda, rpiB, zwf, mopA, pstA, pstB, pstC,

pstS, ugpB, ugpA, ugpE, ugpC, ugpQ, dnaK, dnaJ, clpB, rpoE, htpG, ompF, ompC, aspA, gltA, sdhB, aceB and aceK.

The nucleotide sequences of the genes of *Escherichia coli* belong to the prior art and can also be found in the genome  
5 sequence of *Escherichia coli* published by Blattner et al. (Science 277: 1453-1462 (1997)).

phoA gene:

Description: Alkaline phosphatase

EC No.: 3.1.3.1

10 Reference: Berg; Journal of Bacteriology 146(2): 660-667 (1981)

Accession No.: AE000145

phnC gene:

Description: ATP-binding protein of the alkyl  
15 phosphonate transport system

Reference: Makino et al.; Journal of Bacteriology 173(8): 2665-2672 (1991)

Accession No.: AE000482

phnD gene:

20 Description: Substrate-binding protein of the alkyl phosphonate transport system

Reference: Makino et al.; Journal of Bacteriology 173(8): 2665-2672 (1991)

Accession No.: AE000482

25 Alternative gene name: psiD

phnE gene:

Description: Permease protein of the alkyl phosphonate transport system

Reference: Makino et al.; Journal of Bacteriology  
30 173(8): 2665-2672 (1991)

Accession No.: AE000482

phnF gene:

Description: Putative regulatory protein

Reference: Makino et al.; Journal of Bacteriology  
173(8): 2665-2672 (1991)

Accession No.: AE000482

phnG gene:

5 Description: Membrane-bound sub-unit of the carbon-phosphorus lyase complex

Reference: Makino et al.; Journal of Bacteriology  
173(8): 2665-2672 (1991)

Accession No.: AE000482

10 phnJ gene:

Description: Membrane-bound sub-unit of the carbon-phosphorus lyase complex

Reference: Makino et al.; Journal of Bacteriology  
173(8): 2665-2672 (1991)

15 Accession No.: AE000482

phnK gene:

Description: ATP-binding protein of the phosphonate transporter

20 Reference: Makino et al.; Journal of Bacteriology  
173(8): 2665-2672 (1991)

Accession No.: AE000482

phnL gene:

Description: ATP-binding protein of the phosphonate transporter

25 Reference: Makino et al.; Journal of Bacteriology  
173(8): 2665-2672 (1991)

Accession No.: AE000482

phnM gene:

30 Description: Membrane-bound sub-unit of the carbon-phosphorus lyase complex

Reference: Makino et al.; Journal of Bacteriology  
173(8): 2665-2672 (1991)

Accession No.: AE000482



## phnN gene:

Description: ATP-binding protein of the phosphonate transporter

5 Reference: Makino et al.; Journal of Bacteriology  
173(8): 2665-2672 (1991)

Accession No.: AE000482

## phnO gene:

Description: Putative regulator of the carbon-phosphorus lyase complex

10 Reference: Makino et al.; Journal of Bacteriology  
173(8): 2665-2672 (1991)

Accession No.: AE000482

## phnP gene:

15 Description: Membrane-bound sub-unit of the carbon-phosphorus lyase complex

Reference: Makino et al.; Journal of Bacteriology  
173(8): 2665-2672 (1991)

Accession No.: AE000482

## eda gene:

20 Description: 2-Keto-3-deoxygluconate 6-phosphate aldolase and 2-keto-4-hydroxyglutarate aldolase (Entner-Doudoroff aldolase)

EC No.: 4.1.2.14  
4.1.3.16

25 Reference: Carter et al.; Gene 130(1): 155-156 (1993)

Accession No.: AE000279

Alternative gene names: hga, kdgA

## rpiB gene:

Description: Ribose 5-phosphate isomerase B

30 EC No.: 5.3.1.6

Reference: Sorensen und Hove-Jensen; Journal of Bacteriology 178(4): 1003-1011 (1996)

Accession No.: AE000482

## zwf gene:

Description: Glucose 6-phosphate 1-dehydrogenase  
EC No.: 1.1.1.49  
Reference: Rowley and Wolf; Journal of Bacteriology  
5 173(3): 968-977 (1991)  
Accession No.: AE000279

## mopA gene:

Description: Chaperone GroEL, heat shock protein Hsp60  
Reference: Chandrasekhar et al.; Journal of Biological  
10 Chemistry 261(26): 12414-12419 (1986)  
Accession No.: AE000487  
Alternative gene names: groE, groEL, hdh, tabB

## pstA gene:

Description: Permease protein of the high-affinity  
15 phosphate transport system  
Reference: Surin et al.; Journal of Bacteriology  
161(1): 189-198 (1985); Amemura et al.;  
Journal of Molecular Biology 184(2): 241-  
250 (1985)  
20 Accession No.: AE000449  
Alternative gene names: R2pho, phoR2b, phoT

## pstB gene:

Description: ATP-binding component of the high-affinity  
phosphate transport system  
25 Reference: Surin et al.; Journal of Bacteriology  
161(1): 189-198 (1985); Amemura et al.;  
Journal of Molecular Biology 184(2): 241-  
250 (1985)  
Accession No.: AE000449  
30 Alternative gene name: phoT

## pstC gene:

Description: Permease protein of the high-affinity  
phosphate transport system

Reference: Surin et al.; Journal of Bacteriology  
161(1): 189-198 (1985)

Accession No.: AE000449

Alternative gene name: phoW

5 pstS gene:

Description: Periplasmic phosphate-binding protein of  
the high-affinity phosphate transport  
system

Reference: Surin et al., Journal of Bacteriology  
10 157(3): 772-778 (1984); Magota et al.,  
Journal of Bacteriology 157(3): 909-917  
(1984)

Accession No.: AE000449

Alternative gene names: R2pho, nmpA, phoR2a, phoS

15 ugpB gene:

Description: Periplasmic binding protein of the sn-  
glycerol 3-phosphate transport system

Reference: Overduin et al.; Molecular Microbiology  
2(6): 767-775 (1988); Xavier et al.;  
20 Journal of Bacteriology 177(3): 699-704  
(1995); Schweizer and Boos; Molecular and  
General Genetics 197(1): 161-168 (1984)

Accession No.: AE000421

Alternative gene names: psiB, psiC,

25 ugpA gene:

Description: Permease protein of the sn-glycerol 3-  
phosphate transport system

Reference: Overduin et al.; Molecular Microbiology  
2(6): 767-775 (1988); Xavier et al.;  
30 Journal of Bacteriology 177(3): 699-704  
(1995)

Accession No.: AE000421

Alternative gene names: psiB, psiC

## ugpE gene:

Description: Permease protein of the sn-glycerol 3-phosphate transport system

Reference: Overduin et al.; Molecular Microbiology  
5 2(6): 767-775 (1988); Xavier et al.;  
Journal of Bacteriology 177(3): 699-704  
(1995)

Accession No.: AE000421

## ugpC gene:

10 Description: ATP-binding component of the sn-glycerol 3-phosphate transport system

Reference: Overduin et al.; Molecular Microbiology  
2(6): 767-75 (1988); Xavier et al.; Journal  
of Bacteriology 177(3): 699-704 (1995);  
15 Hekstra and Tommassen; Journal of  
Bacteriology 175(20): 6546-6552 (1993)

Accession No.: AE000421

## ugpQ gene:

Description: Glycerol phosphodiester phosphodiesterase

20 EC No.: 3.1.4.46

Reference: Kasahara et al.; Nucleic Acids Research  
17(7): 2854 (1989); Brzoska and Boos; FEMS  
Microbiology Reviews 5(1-2): 115-124 (1989)

Accession No.: AE000421

## 25 dnaK gene:

Description: Autoregulated heat shock protein Hsp70

Reference: Bardwell and Craig; Proceedings of the  
National Academy of Sciences of the United  
States of America 81(3): 848-52 (1984)

30 Accession No.: AE000112

Alternative gene names: gro, groP, groPAB, groPC, groPF,  
rpC, grpF, seg

## dnaJ gene:

Description: Chaperone; heat shock protein

Reference: Ohki et al.; Journal of Biological  
Chemistry 261(4): 1778-1781 (1986)

Accession No.: AE000112

Alternative gene names: groP, grpC

5 clpB gene:

Description: Heat shock protein f84.1

Reference: Kitagawa et al.; Journal of Bacteriology  
173(14): 4247-4253 (1991)

Accession No.: AE000345

10 Alternative gene name: htpM

rpoE gene:

Description: Sigma-E sub-unit of RNA polymerase

Reference: Raina et al.; EMBO Journal 14(5): 1043-1055  
(1995)

15 Accession No.: AE000343

Alternative gene name: sigE

htpG gene:

Description: Chaperone; heat shock protein c62.5

Reference: Spence and Georgopoulos; Journal of  
20 Biological Chemistry 264(8): 4398-4403  
(1989); Bardwell and Craig; Proceedings of  
the National Academy of Sciences of the  
United States of America 84(15): 5177-5181  
(1987)

25 Accession No.: AE000153

ompF gene:

Description: Outer membrane protein F(= 1a; ia; B)

Reference: Inokuchi et al.; Nucleic Acids Research  
10(21): 6957-6968 (1982)

30 Accession No.: AE000195

Alternative gene names: cmlB, coa, cry, tolF

ompC gene:

Description: Outer membrane protein C (= 1b)

Reference: Mizuno et al.; Journal of Biological  
Chemistry 258(11): 6932-6940 (1983)

Accession No.: AE000310

Alternative gene names: meoA, par

5 aspA gene:

Description: Aspartate ammonium lyase (aspartase)

EC No.: 4.3.1.1

Reference: Takagi et al.; Nucleic Acids Research  
13(6): 2063-2074 (1985); Woods et al.;

10 Biochemical Journal 237(2): 547-557 (1986);

Falzone et al.; Biochemistry 27(26): 9089-  
9093 (1988); Jayasekera et al.;

Biochemistry 36(30): 9145-9150 (1997)

Accession No.: AE000486

15 gltA gene:

Description: Citrate synthase

EC No.: 4.1.3.7

Reference: Spencer and Guest, Journal of Bacteriology  
151(2): 542-552 (1982)

20 Accession No.: AE000175

Alternative gene names: gluT, icdB

sdhB gene:

Description: Iron-sulfur protein sub-unit of succinate  
dehydrogenase

25 EC No.: 1.3.99.1

Reference: Darlison and Guest, Biochemical Journal  
223(2), 507-517 (1984)

Accession No.: AE000175

aceB gene:

30 Description: Malate synthase A

EC No.: 4.1.3.2

Reference: Byrne et al.; Nucleic Acids Research  
16(19), 9342 (1988); Byrne et al.; Nucleic  
Acids Research 16(22), 10924 (1988); Cortay  
et al.; Biochimie 71(9-10): 1043-9 (1989)

5 Accession No.: AE000474

Alternative gene name: mas

aceK gene:

Description: Isocitrate dehydrogenase kinase/phosphatase

EC No.: 2.7.1.116

10 3.1.3.-

Reference: Cortay et al.; Journal of Bacteriology  
170(1): 89-97 (1988); Klumpp et al.;  
Journal of Bacteriology 170(6): 2763-2769  
(1988); Nelson et al.; Genetics 147(4):  
15 1509-1520 (1997); Laporte et al.; Biochimie  
71(9-10): 1051-7 (1989)

Accession No.: AE000474

The nucleic acid sequences can be found in the databanks of  
the National Center for Biotechnology Information (NCBI) of  
20 the National Library of Medicine (Bethesda, MD, USA), the  
nucleotide sequence databank of the European Molecular  
Biologies Laboratories (EMBL, Heidelberg, Germany or  
Cambridge, UK) or the DNA databank of Japan (DDBJ, Mishima,  
Japan).

25 The genes described in the text references mentioned can be  
used according to the invention. Alleles of the genes which  
result from the degeneracy of the genetic code or due to  
"sense mutations" of neutral function can furthermore be  
used.

30 To achieve an enhancement, for example, expression of the  
genes or the catalytic properties of the proteins can be  
increased. The two measures can optionally be combined.

To achieve an over-expression, the number of copies of the corresponding genes can be increased, or the promoter and regulation region or the ribosome binding site upstream of the structural gene can be mutated. Expression cassettes  
5 which are incorporated upstream of the structural gene act in the same way. By inducible promoters, it is additionally possible to increase the expression in the course of fermentative L-threonine production. The expression is likewise improved by measures to prolong the  
10 life of the m-RNA. Furthermore, the enzyme activity is also increased by preventing the degradation of the enzyme protein. The genes or gene constructs can either be present in plasmids with a varying number of copies, or can be integrated and amplified in the chromosome.  
15 Alternatively, an over-expression of the genes in question can furthermore be achieved by changing the composition of the media and the culture procedure.

Instructions in this context can be found by the expert, inter alia, in Chang and Cohen (Journal of Bacteriology  
20 134: 1141-1156 (1978)), in Hartley and Gregori (Gene 13: 347-353 (1981)), in Amann and Brosius (Gene 40: 183-190 (1985)), in de Broer et al. (Proceedings of the National Academy of Sciences of the United States of America 80: 21-25 (1983)), in LaVallie et al. (BIO/TECHNOLOGY 11: 187-193  
25 (1993)), in PCT/US97/13359, in Llosa et al. (Plasmid 26: 222-224 (1991)), in Quandt and Klipp (Gene 80: 161-169 (1989)), in Hamilton et al. (Journal of Bacteriology 171: 4617-4622 (1989)), in Jensen and Hammer (Biotechnology and Bioengineering 58: 191-195 (1998)) and in known textbooks  
30 of genetics and molecular biology.

Plasmid vectors which are capable of replication in Enterobacteriaceae, such as e.g. cloning vectors derived from pACYC184 (Bartolomé et al.; Gene 102: 75-78 (1991)), pTrc99A (Amann et al.; (Gene 69: 301-315 (1988)) or pSC101  
35 derivatives (Vocke and Bastia, Proceedings of the National



Academy of Sciences USA 80 (21): 6557-6561 (1983)) can be used. A strain transformed with a plasmid vector, where the plasmid vector carries at least one or more of the genes chosen from the group consisting of phoA, phnC, phnD,  
5 phnE, phnF, phnG, phnJ, phnK, phnL, phnM, phnN, phnO, phnP, eda, rpiB, zwf, mopA, pstA, pstB, pstC, pstS, ugpB, ugpA, ugpE, ugpC, ugpQ, dnaK, dnaJ, clpB, rpoE, htpG, ompF, ompC, aspA, gltA, sdhB, aceB and aceK, or nucleotide sequences which code for these, can be employed in a process  
10 according to the invention.

It is also possible to transfer mutations which affect the expression of the particular gene into various strains by sequence exchange (Hamilton et al.; Journal of Bacteriology 171: 4617-4622 (1989)), conjugation or transduction.

15 It may furthermore be advantageous for the production of L-amino acids, in particular L-threonine, with strains of the Enterobacteriaceae family, in addition to enhancement of one or more of the genes chosen from the group consisting of phoA, phnC, phnD, phnE, phnF, phnG, phnJ, phnK, phnL,  
20 phnM, phnN, phnO, phnP, eda, rpiB, zwf, mopA, pstA, pstB, pstC, pstS, ugpB, ugpA, ugpE, ugpC, ugpQ, dnaK, dnaJ, clpB, rpoE, htpG, ompF, ompC, aspA, gltA, sdhB, aceB and aceK, for one or more enzymes of the known threonine biosynthesis pathway or enzymes of anaplerotic metabolism or enzymes for  
25 the production of reduced nicotinamide adenine dinucleotide phosphate or enzymes of glycolysis or PTS enzymes or enzymes of sulfur metabolism to be enhanced.

Thus, for example, at the same time one or more of the genes chosen from the group consisting of

- 30 • the thrABC operon which codes for aspartate kinase, homoserine dehydrogenase, homoserine kinase and threonine synthase (US-A-4,278,765),

- the *pyc* gene of *Corynebacterium glutamicum* which codes for pyruvate carboxylase (WO 99/18228),
- the *pps* gene which codes for phosphoenol pyruvate synthase (Molecular and General Genetics 231(2): 332-336 (1992)),  
5
- the *ppc* gene which codes for phosphoenol pyruvate carboxylase (Gene 31: 279-283 (1984)),
- the *pntA* and *pntB* genes which code for transhydrogenase (European Journal of Biochemistry 158: 647-653 (1986)),
- 10 • the *rhtB* gene which imparts homoserine resistance (EP-A-0 994 190),
- the *mgo* gene which codes for malate:quinone oxidoreductase (WO 02/06459),
- the *rhtC* gene which imparts threonine resistance (EP-A-1  
15 013 765),
- the *thrE* gene of *Corynebacterium glutamicum* which codes for the threonine export protein (WO 01/92545),
- the *gdhA* gene which codes for glutamate dehydrogenase (Nucleic Acids Research 11: 5257-5266 (1983); Gene 23:  
20 199-209 (1983)),
- the *hns* gene which codes for the DNA-binding protein HLP-II (Molecular and General Genetics 212: 199-202 (1988)),
- the *pgm* gene which codes for phosphoglucomutase (Journal  
25 of Bacteriology 176: 5847-5851 (1994)),
- the *fba* gene which codes for fructose biphosphate aldolase (Biochemical Journal 257: 529-534 (1989)),
- the *ptsH* gene of the *ptsHIcrr* operon which codes for the phosphohistidine protein hexose phosphotransferase of

the phosphotransferase system PTS (Journal of Biological Chemistry 262: 16241-16253 (1987)),

- the ptsI gene of the ptsHICrr operon which codes for enzyme I of the phosphotransferase system PTS (Journal of Biological Chemistry 262: 16241-16253 (1987)),
- the crr gene of the ptsHICrr operon which codes for the glucose-specific IIA component of the phosphotransferase system PTS (Journal of Biological Chemistry 262: 16241-16253 (1987)),
- the ptsG gene which codes for the glucose-specific IIBC component (Journal of Biological Chemistry 261: 16398-16403 (1986)),
- the lrp gene which codes for the regulator of the leucine regulon (Journal of Biological Chemistry 266: 10768-10774 (1991)),
- the mopB gene which codes for 10 Kd chaperone (Journal of Biological Chemistry 261: 12414-12419 (1986)) and is also known by the name groES,
- the ahpC gene of the ahpCF operon which codes for the small sub-unit of alkyl hydroperoxide reductase (Proceedings of the National Academy of Sciences of the United States of America 92: 7617-7621 (1995)),
- the ahpF gene of the ahpCF operon which codes for the large sub-unit of alkyl hydroperoxide reductase (Proceedings of the National Academy of Sciences of the United States of America 92: 7617-7621 (1995)),
- the cysK gene which codes for cysteine synthase A (Journal of Bacteriology 170: 3150-3157 (1988)),
- the cysB gene which codes for the regulator of the cys regulon (Journal of Biological Chemistry 262: 5999-6005 (1987)),

- the *cysJ* gene of the *cysJIH* operon which codes for the flavoprotein of NADPH sulfite reductase (Journal of Biological Chemistry 264: 15796-15808 (1989), Journal of Biological Chemistry 264: 15726-15737 (1989)),
- 5 • the *cysI* gene of the *cysJIH* operon which codes for the haemoprotein of NADPH sulfite reductase (Journal of Biological Chemistry 264: 15796-15808 (1989), Journal of Biological Chemistry 264: 15726-15737 (1989)),
- 10 • the *cysH* gene of the *cysJIH* operon which codes for adenylyl sulfate reductase (Journal of Biological Chemistry 264: 15796-15808 (1989), Journal of Biological Chemistry 264: 15726-15737 (1989)),
- the *malE* gene which codes for the periplasmic binding protein of maltose transport (Journal of Biological Chemistry 259 (16): 10606-10613 (1984)),
- 15 • the *phoB* gene of the *phoBR* operon which codes for the positive regulator PhoB of the *pho* regulon (Journal of Molecular Biology 190 (1): 37-44 (1986)),
- the *phoR* gene of the *phoBR* operon which codes for the sensor protein of the *pho* regulon (Journal of Molecular Biology 192 (3): 549-556 (1986)),
- 20 • the *phoE* gene which codes for protein E of the outer cell membrane (Journal of Molecular Biology 163 (4): 513-532 (1983)),
- 25 • the *pykF* gene which codes for fructose-stimulated pyruvate kinase I (Journal of Bacteriology 177 (19): 5719-5722 (1995)),
- the *pfkB* gene which codes for 6-phosphofructokinase II (Gene 28 (3): 337-342 (1984)),
- 30 • the *talB* gene which codes for transaldolase B (Journal of Bacteriology 177 (19): 5719-5722 (1995))

- the rseA gene of the rseABC operon which codes for a membrane protein with anti-sigmaE activity (Molecular Microbiology 24 (2): 355-371 (1997)),
- the rseC gene of the rseABC operon which codes for a  
5 global regulator of the sigmaE factor (Molecular Microbiology 24 (2): 355-371 (1997)),
- the sodA gene which codes for superoxide dismutase (Journal of Bacteriology 155 (3): 1078-1087 (1983)),
- the sucA gene of the sucABCD operon which codes for the  
10 decarboxylase sub-unit of 2-ketoglutarate dehydrogenase (European Journal of Biochemistry 141 (2): 351-359 (1984)),
- the sucB gene of the sucABCD operon which codes for the  
15 dihydrolipoyltranssuccinase E2 sub-unit of 2-ketoglutarate dehydrogenase (European Journal of Biochemistry 141 (2): 361-374 (1984)),
- the sucC gene of the sucABCD operon which codes for the  $\beta$ -sub-unit of succinyl-CoA synthetase (Biochemistry 24 (22): 6245-6252 (1985)) and
- 20 • the sucD gene of the sucABCD operon which codes for the  $\alpha$ -sub-unit of succinyl-CoA synthetase (Biochemistry 24 (22): 6245-6252 (1985)),

can be enhanced, in particular over-expressed.

It may furthermore be advantageous for the production of L-  
25 amino acids, in particular L-threonine, in addition to enhancement of one or more of the genes chosen from the group consisting of phoA, phnC, phnD, phnE, phnF, phnG, phnJ, phnK, phnL, phnM, phnN, phnO, phnP, eda, rpiB, zwf, mopA, pstA, pstB, pstC, pstS, ugpB, ugpA, ugpE, ugpC, ugpQ,  
30 dnaK, dnaJ, clpB, rpoE, htpG, ompF, ompC, aspA, gltA, sdhB,

aceB and aceK, for one or more of the genes chosen from the group consisting of

- the tdh gene which codes for threonine dehydrogenase (Journal of Bacteriology 169: 4716-4721 (1987)),
- 5 • the mdh gene which codes for malate dehydrogenase (E.C. 1.1.1.37) (Archives in Microbiology 149: 36-42 (1987)),
- the gene product of the open reading frame (orf) yjfA (Accession Number AAC77180 of the National Center for Biotechnology Information (NCBI, Bethesda, MD, USA)),
- 10 • the gene product of the open reading frame (orf) ytfP (Accession Number AAC77179 of the National Center for Biotechnology Information (NCBI, Bethesda, MD, USA)),
- the pckA gene which codes for the enzyme phosphoenolpyruvate carboxykinase (Journal of Bacteriology 172: 15 7151-7156 (1990)),
- the poxB gene which codes for pyruvate oxidase (Nucleic Acids Research 14(13): 5449-5460 (1986)),
- the aceA gene which codes for the enzyme isocitrate lyase (Journal of Bacteriology 170: 4528-4536 (1988)),
- 20 • the dgsA gene which codes for the DgsA regulator of the phosphotransferase system (Bioscience, Biotechnology and Biochemistry 59: 256-251 (1995)) and is also known under the name of the mlc gene,
- the fruR gene which codes for the fructose repressor 25 (Molecular and General Genetics 226: 332-336 (1991)) and is also known under the name of the cra gene and
- the rpoS gene which codes for the sigma<sup>38</sup> factor (WO 01/05939) and is also known under the name of the katF gene,

to be attenuated, in particular eliminated or for the expression thereof to be reduced.

The term "attenuation" in this connection describes the reduction or elimination of the intracellular activity of one or more enzymes (proteins) in a microorganism which are coded by the corresponding DNA, for example by using a weak promoter or a gene or allele which codes for a corresponding enzyme with a low activity or inactivates the corresponding enzyme (protein) or gene, and optionally combining these measures.

By attenuation measures, the activity or concentration of the corresponding protein is in general reduced to 0 to 75%, 0 to 50%, 0 to 25%, 0 to 10% or 0 to 5% of the activity or concentration of the wild-type protein or of the activity or concentration of the protein in the starting microorganism.

It may furthermore be advantageous for the production of L-amino acids, in particular L-threonine, in addition to enhancement of one or more of the genes chosen from the group consisting of phoA, phnC, phnD, phnE, phnF, phnG, phnJ, phnK, phnL, phnM, phnN, phnO, phnP, eda, rpiB, zwf, mopA, pstA, pstB, pstC, pstS, ugpB, ugpA, ugpE, ugpC, ugpQ, dnaK, dnaJ, clpB, rpoE, htpG, ompF, ompC, aspA, gltA, sdhB, aceB and aceK, to eliminate undesirable side reactions (Nakayama: "Breeding of Amino Acid Producing Microorganisms", in: Overproduction of Microbial Products, Krumphanzl, Sikyta, Vanek (eds.), Academic Press, London, UK, 1982).

The microorganisms produced according to the invention can be cultured in the batch process (batch culture), the fed batch (feed process) or the repeated fed batch process (repetitive feed process). A summary of known culture methods is described in the textbook by Chmiel (Bioprozesstechnik 1. Einführung in die

Bioverfahrenstechnik [Bioprocess Technology 1. Introduction to Bioprocess Technology (Gustav Fischer Verlag, Stuttgart, 1991)) or in the textbook by Storhas (Bioreaktoren und periphere Einrichtungen [Bioreactors and Peripheral  
5 Equipment] (Vieweg Verlag, Braunschweig/Wiesbaden, 1994)).

The culture medium to be used must meet the requirements of the particular strains in a suitable manner. Descriptions of culture media for various microorganisms are contained in the handbook "Manual of Methods for General  
10 Bacteriology" of the American Society for Bacteriology (Washington D.C., USA, 1981).

Sugars and carbohydrates, such as e.g. glucose, sucrose, lactose, fructose, maltose, molasses, starch and optionally cellulose, oils and fats, such as e.g. soya oil, sunflower  
15 oil, groundnut oil and coconut fat, fatty acids, such as e.g. palmitic acid, stearic acid and linoleic acid, alcohols, such as e.g. glycerol and ethanol, and organic acids, such as e.g. acetic acid, can be used as the source of carbon. These substances can be used individually or as  
20 a mixture.

Organic nitrogen-containing compounds, such as peptones, yeast extract, meat extract, malt extract, corn steep liquor, soya bean flour and urea, or inorganic compounds, such as ammonium sulfate, ammonium chloride, ammonium  
25 phosphate, ammonium carbonate and ammonium nitrate, can be used as the source of nitrogen. The sources of nitrogen can be used individually or as a mixture.

Phosphoric acid, potassium dihydrogen phosphate or dipotassium hydrogen phosphate or the corresponding sodium-  
30 containing salts can be used as the source of phosphorus. The culture medium must furthermore comprise salts of metals, such as e.g. magnesium sulfate or iron sulfate, which are necessary for growth. Finally, essential growth substances, such as amino acids and vitamins, can be



employed in addition to the abovementioned substances.  
Suitable precursors can moreover be added to the culture medium. The starting substances mentioned can be added to the culture in the form of a single batch, or can be fed in  
5 during the culture in a suitable manner.

Basic compounds, such as sodium hydroxide, potassium hydroxide, ammonia or aqueous ammonia, or acid compounds, such as phosphoric acid or sulfuric acid, can be employed in a suitable manner to control the pH of the culture.  
10 Antifoams, such as e.g. fatty acid polyglycol esters, can be employed to control the development of foam. Suitable substances having a selective action, e.g. antibiotics, can be added to the medium to maintain the stability of plasmids. To maintain aerobic conditions, oxygen or  
15 oxygen-containing gas mixtures, such as e.g. air, are introduced into the culture. The temperature of the culture is usually 25°C to 45°C, and preferably 30°C to 40°C. Culturing is continued until a maximum of L-amino acids or L-threonine has formed. This target is usually  
20 reached within 10 hours to 160 hours.

The analysis of L-amino acids can be carried out by anion exchange chromatography with subsequent ninhydrin derivatization, as described by Spackman et al. (Analytical Chemistry 30: 1190-1206 (1958)), or it can take place by  
25 reversed phase HPLC as described by Lindroth et al. (Analytical Chemistry 51: 1167-1174 (1979)).

The process according to the invention is used for the fermentative preparation of L-amino acids, such as, for example, L-threonine, L-isoleucine, L-valine, L-methionine,  
30 L-homoserine and L-lysine, in particular L-threonine.

**What is claimed is:**

1. A process for the preparation of L-amino acids, in particular L-threonine, which comprises carrying out the following steps:
  - 5 a) fermentation of microorganisms of the Enterobacteriaceae family which produce the desired L-amino acid and in which one or more of the genes chosen from the group consisting of phoA, phnC, phnD, phnE, phnF, phnG, phnJ, phnK, phnL, phnM,  
10 phnN, phnO, phnP, eda, rpiB, zwf, mopA, pstA, pstB, pstC, pstS, ugpB, ugpA, ugpE, ugpC, ugpQ, dnaK, dnaJ, clpB, rpoE, htpG, ompF, ompC, aspA, gltA, sdhB, aceB and aceK, or nucleotide sequences which code for these, is or are enhanced, in particular  
15 over-expressed,
  - b) concentration of the desired L-amino acid in the medium or in the cells of the microorganisms, and
  - c) isolation of the desired L-amino acid, constituents  
20 of the fermentation broth and/or the biomass in its entirety or portions (> 0 to 100 %) thereof optionally remaining in the product.
2. A process as claimed in claim 1, wherein microorganisms in which further genes of the biosynthesis pathway of the desired L-amino acid are additionally enhanced are  
25 employed.
3. A process as claimed in claim 1, wherein microorganisms in which the metabolic pathways which reduce the formation of the desired L-amino acid are at least partly eliminated are employed.
- 30 4. A process as claimed in claim 1, wherein the expression of the polynucleotide (s) which code(s) for one or more of the genes chosen from the group consisting of phoA,

phnC, phnD, phnE, phnF, phnG, phnJ, phnK, phnL, phnM,  
phnN, phnO, phnP, eda, rpiB, zwf, mopA, pstA, pstB,  
pstC, pstS, ugpB, ugpA, ugpE, ugpC, ugpQ, dnaK, dnaJ,  
clpB, rpoE, htpG, ompF, ompC, aspA, gltA, sdhB, aceB  
5 and aceK is increased.

5. A process as claimed in claim 1, wherein the regulatory  
and/or catalytic properties of the polypeptides  
(proteins) for which the polynucleotides phoA, phnC,  
phnD, phnE, phnF, phnG, phnJ, phnK, phnL, phnM, phnN,  
10 phnO, phnP, eda, rpiB, zwf, mopA, pstA, pstB, pstC,  
pstS, ugpB, ugpA, ugpE, ugpC, ugpQ, dnaK, dnaJ, clpB,  
rpoE, htpG, ompF, ompC, aspA, gltA, sdhB, aceB and aceK  
code are improved or increased.

6. A process as claimed in claim 1, wherein, for the  
15 preparation of L-amino acids, microorganisms of the  
Enterobacteriaceae family in which in addition at the  
same time one or more of the genes chosen from the  
group consisting of:

6.1 the thrABC operon which codes for aspartate  
20 kinase, homoserine dehydrogenase, homoserine  
kinase and threonine synthase,

6.2 the pyc gene which codes for pyruvate  
carboxylase,

6.3 the pps gene which codes for phosphoenol  
25 pyruvate synthase,

6.4 the ppc gene which codes for phosphoenol  
pyruvate carboxylase,

6.5 the pntA and pntB genes which code for  
transhydrogenase,

6.6 the rhtB gene which imparts homoserine  
30 resistance,

- 6.7 the mgo gene which codes for malate:quinone oxidoreductase,
- 6.8 the rhtC gene which imparts threonine resistance,
- 5 6.9 the thrE gene which codes for the threonine export protein,
- 6.10 the gdhA gene which codes for glutamate dehydrogenase,
- 10 6.11 the hns gene which codes for the DNA-binding protein HLP-II,
- 6.12 the pgm gene which codes for phosphoglucomutase,
- 6.13 the fba gene which codes for fructose biphosphate aldolase,
- 15 6.14 the ptsH gene which codes for the phosphohistidine protein hexose phosphotransferase,
- 6.15 the ptsI gene which codes for enzyme I of the phosphotransferase system,
- 20 6.16 the crr gene which codes for the glucose-specific IIA component,
- 6.17 the ptsG gene which codes for the glucose-specific IIBC component,
- 25 6.18 the lrp gene which codes for the regulator of the leucine regulon,
- 6.19 the mopB gene which codes for 10 Kd chaperone,
- 6.20 the ahpC gene which codes for the small sub-unit of alkyl hydroperoxide reductase,

- 6.21 the ahpF gene which codes for the large sub-unit of alkyl hydroperoxide reductase,
- 6.22 the cysK gene which codes for cysteine synthase A,
- 5 6.23 the cysB gene which codes for the regulator of the cys regulon,
- 6.24 the cysJ gene which codes for the flavoprotein of NADPH sulfite reductase,
- 10 6.25 the cysI gene which codes for the haemoprotein of NADPH sulfite reductase,
- 6.26 the cysH gene which codes for adenylyl sulfate reductase,
- 6.27 the malE gene which codes for the periplasmic binding protein of maltose transport,
- 15 6.28 the phoB gene which codes for the positive regulator PhoB of the pho regulon,
- 6.29 the phoR gene which codes for the sensor protein of the pho regulon,
- 6.30 the phoE gene which codes for protein E of outer cell membrane,
- 20 6.31 the pykF gene which codes for fructose-stimulated pyruvate kinase I,
- 6.32 the pfkB gene which codes for 6-phosphofructokinase II,
- 25 6.33 the talB gene which codes for transaldolase B,
- 6.34 the rseA gene which codes for a membrane protein which acts as a negative regulator on sigmaE activity,

- 6.35 the rseC gene which codes for a global  
regulator of the sigmaE factor,
- 6.36 the sodA gene which codes for superoxide  
dismutase,
- 5 6.37 the sucA gene which codes for the decarboxylase  
sub-unit of 2-ketoglutarate dehydrogenase,
- 6.38 the sucB gene which codes for the  
dihydrolipoyltranssuccinase E2 sub-unit of 2-  
ketoglutarate dehydrogenase,
- 10 6.39 the sucC gene which codes for the  $\beta$ -sub-unit of  
succinyl-CoA synthetase,
- 6.40 the sucD gene which codes for the  $\alpha$ -sub-unit of  
succinyl-CoA synthetase,
- 15 is or are enhanced, in particular over-expressed, are  
fermented.
7. A process as claimed in claim 1, wherein, for the  
préparation of L-amino acids, microorganisms of the  
Enterobacteriaceae family in which in addition at the  
same time one or more of the genes chosen from the  
20 group consisting of:
- 7.1 the tdh gene which codes for threonine  
dehydrogenase,
- 7.2 the mdh gene which codes for malate  
dehydrogenase,
- 25 7.3 the gene product of the open reading frame  
(orf) yjfA,
- 7.4 the gene product of the open reading frame  
(orf) ytfP,

- 7.5 the pckA gene which codes for phosphoenol  
pyruvate carboxykinase,
- 7.6 the poxB gene which codes for pyruvate oxidase,
- 7.7 the aceA gene which codes for isocitrate lyase,
- 5 7.8 the dgsA gene which codes for the DgsA  
regulator of the phosphotransferase system,
- 7.9 the fruR gene which codes for the fructose  
repressor,
- 10 7.10 the rpoS gene which codes for the sigma<sup>38</sup>  
factor

is or are attenuated, in particular eliminated or  
reduced in expression, are fermented.

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(54) Title: PROCESS FOR THE PREPARATION OF L-AMINO ACIDS USING STRAINS OF THE ENTEROBACTERIACEAE FAMILY

(57) Abstract: The invention relates to a process for the preparation of L-amino acids, in particular L-threonine, in which the following steps are carried out: a) fermentation of microorganisms of the Enterobacteriaceae family which produce the desired L-amino acid and in which at least one or more of the genes chosen from the group consisting of phoA, phnC, phnD, phnE, phnF, phnG, phnJ, phnK, phnL, phnM, phnN, phnO, phnP, eda, rpiB, zwf, mopA, pstA, pstB, pstC, pstS, ugpB, ugpA, ugpE, ugpC, ugpQ, dnaK, dnaJ, clpB, rpoE, htpG, ompF, ompC, aspA, gltA, sdhB, aceB and aceK, or nucleotide sequences which code for these, is or are enhanced, in particular over-expressed, b) concentration of the desired L-amino acid in the medium or in the cells of the bacteria, and c) isolation of the desired L-amino acid.



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International Application No

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## A. CLASSIFICATION OF SUBJECT MATTER

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Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, BIOSIS, MEDLINE, EMBASE

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WANNER B L: "Gene regulation by phosphate in enteric bacteria." JOURNAL OF CELLULAR BIOCHEMISTRY, vol. 51, no. 1, January 1993 (1993-01), pages 47-54, XP008018017 ISSN: 0730-2312 the whole document	1-7
A	TORRIANI A: "From cell membrane to nucleotides: the phosphate regulon in Escherichia coli." BIOESSAYS: NEWS AND REVIEWS IN MOLECULAR, CELLULAR AND DEVELOPMENTAL BIOLOGY, vol. 12, no. 8, August 1990 (1990-08), pages 371-376, XP008018018 ISSN: 0265-9247 the whole document	1-7

☒ Further documents are listed in the continuation of box C.☒ Patent family members are listed in annex.

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PCT/EP 02/07356

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
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# INTERNATIONAL SEARCH REPORT

International application No.  
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## Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:  
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:  
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:
3. ☐ Claims Nos.:  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

## Box II Observations where unity of invention is lacking (Continuation of Item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-7 all partially

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest.  
☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

Invention 1, claims 1-7 (all partially)

A process for the preparation of L-amino acids, in particular L-threonine, comprising the steps of a) fermenting a microorganism of the Enterobacteriaceae family which produces the desired L-amino acid and in which the phoA gene is enhanced, in particular overexpressed, b) concentrating and (c) isolating the desired L-amino acid, as well as a process as said in which additional genes are enhanced and/or attenuated.

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Inventions 2-38, claims 1-7 (all partially)

As invention 1, but with the following genes being enhanced, respectively: phnC, phnD, phnE, phnF, phnG, phnJ, phnK, phnL, phnM, phnN, phnO, phnP, eda, rpiB, zwf, mopA, pstA, pstB, pstC, pstS, ugpB, ugpA, ugpE, ugpC, ugpQ, dnaK, dnaJ, clpB, rpoE, htpG, ompF, ompC, aspA, gltA, sdhB, aceB and aceK.

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